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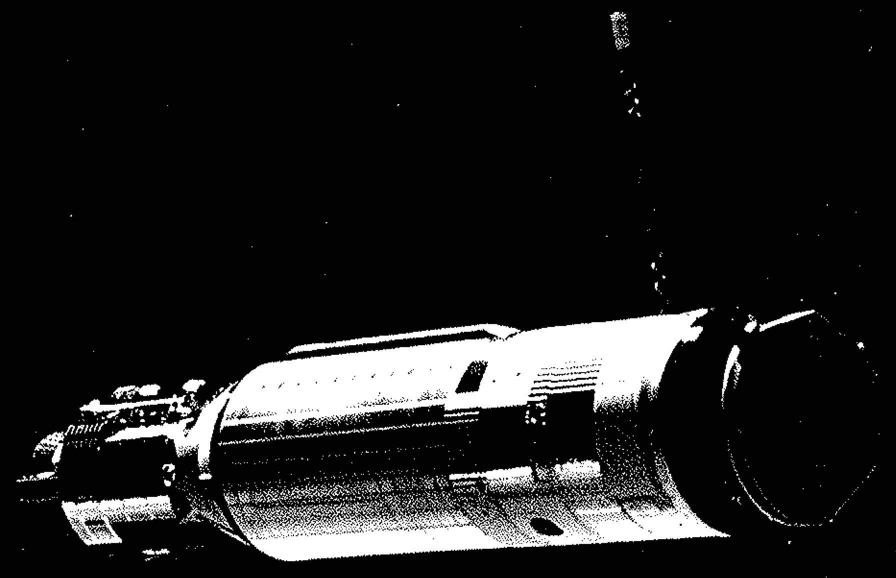

GEMINI VIII

WHAT REALLY HAPPENS WHEN A SPACESUIT FAILS

By Cathleen S. Lewis

Introduction

Last year, when training a new class of docents on our spacesuit collection, one of them asked me what exactly happens when a spacesuit fails or an astronaut experiences explosive decompression while in space? As I am not a medical doctor, I could only answer in generalities and draw on two commonly familiar scenes from popular movies that illustrated the extreme hypothesis of what might happen. The two examples represented the extremes in optimism of the body's ability to survive without oxygen and drama surrounding its immediate effects. They also seemed to me to represent extremes in thoughtfulness as to the conditions in space. Caught unprepared and on the spot my instinct was to trust the least dramatic scenario as being closest to the scientific reality. Upon further research, I found that there have been five, real-life documented examples of spacesuit failure and four led to a consequent extreme depressurization, and one yielded a surprising circumstance. Each case has supported what scientists understand to be the physiological human response and chemical response to the sudden loss of oxygen or major failure in an isolated environment. And I can illustrate each case with artifacts from the Smithsonian National Air and Space Museum's collection of flight and spacesuits.

Mythology in the Movies

Science fiction movies in America don't have an outstanding reputation for scientific and technical accuracy. The advent of computer-generated imagery and the financial incentives for producing summer box-office blockbusters have created few financial incentives for movie directors to concern themselves with science education. The cases in which directors have chosen to confer with experts to make their science fiction films realistic are rare and notable. They stand out against the predominant standard fare of science fiction films in which the scientific literate population must suspend disbelief. The following two examples are films at either end of the spectrum of accuracy. In each case, depressurization and the absence of a spacesuit are essential to the plotline. For better or worse, this represents the range of education among the visitors who come to the museum and view our spacesuit and pressure suit collection.

In the movie *2001: A Space Odyssey*, the astronaut Dave Bowman leaves his mother ship in a shuttle craft in order to retrieve his colleague's body.[1] Unfortunately, he is wearing a pressure suit, but neglects to take his spacesuit helmet. When the computer HAL refuses him return access to the shuttle pod bay for his craft because it knows that he had plotted to turn the computer off, Bowman decides to use the pressure inside the shuttle to propel him through the unpressurized pod bay door. He positions the shuttle in front of the open and vacuous pod bay and in an elegant demonstration of a principle of physics, Bowman rides the wave of air moving from the high pressure of the shuttle to the low (or near zero) pressure of the open to the vacuum of space pod bay. After a bit of bouncing around in weightlessness and within a matter of seconds, he closes the bay doors and re-pressurizes the bay, surviving a few seconds in open space without a helmet. Dave survives, albeit a bit banged around, reenters the ship, and shuts down HAL.

Director Stanley Kubrick is given well-deserved credit for his scientifically informed filmmaking in this movie. He was likely influenced by a Russian tradition in science fiction that had its origins in the 19th century.[2] Konstantin Tsiolkovsky is best known as the "father of Russian" rocketry, but he had also been a promoter of "realistic" science fiction. He encouraged his contemporaries to write science fantasies that strictly adhered to known scientific principles. Tsiolkovsky believed that fantastic tales that were not based on sound technologic principles would fail to encourage young people to participate in science and engineering. That was the major objective of science fiction in his mind. In the late 1960s, Kubrick found himself making a movie based on a book by another proponent of realistic science fiction, Arthur C. Clarke.[3] Clarke had also written the screenplay, assuring that the final product would not deviate from his original intentions.

In contrast to *2001*, the 1990 version of *Total Recall* was a film based on Philip K Dick's short story "We Can Remember It for You Wholesale."[4] The original 1966 story was a psychological thriller about memory and heroism with an ambiguous ending.[5] The screenplay and film were posthumous adaptations that avoided Dick's characteristic dark ending and veered toward an action thriller. The plot adjustment called for a story line that focused more strongly on science fiction and had a more dramatic and longer portrayal of surviving a vacuum than in *2001*. When hero/anti-hero Quaid activates an alien terraforming machine on Mars, he, too rides the wave of emergent air pressure escaping into a vacuum and lands on the surface of the red planet. During the ensuing few minutes of the film, Quaid gasps and tears at his face, which through the miracle of special effect is doing an effective imitation of a "Bug-Out Bob" stress squeeze toy. Within minutes, Mars is miraculously terra-formed, acquires an oxygen atmosphere and turns green. The hero survives.

Real Life Experiences

Given the two film scenarios, would be obvious to even the most naïv viewer that the former portrayal is mo accurate to explain why without reso ing to a lecture on aerospace physiology. Popular culture is littered with urban legends about blood boiling, bodies exploding in vacuums, and other examples of scientific principles simplified and even distorted beyond meaning. However, there are five examples of events that illustrate the realistic, less melodramatic and digitally enhanced, and in some cases equally catastrophic consequences of what really happens when a spacesuit fails.

1960 Joe Kittinger

In 1958, the United States Air Force inaugurated Project Excelsior to test the capabilities of pressure suits for pilots experiencing high-altitude ejections. The high-altitude aircraft that were integral to reconnaissance and surveillance during the Cold War carried pilots to altitudes beyond those previously experienced; beyond the accepted limits of the Earth's atmosphere. One of the suits to be tested was the David Clark Company's MC-3A partial pressure suit (see Figure 1).[6] This was the same type of suit that Gary Powers wore during his ill-fated U-2 flight over the USSR. The David Clark Company had produced the pressure suit, building on the Air Force's previous experience in high–altitude pressure suits.

Instead of having pilots eject from perfectly good aircraft at high altitudes, the Air Force program had parachute specialists jump from increasingly high altitudes from an unpressurized balloon gondolas, to test the performance of the suits. On his third and final jump in the project on 16 August 1960, Joe Kittinger Jr. noticed that he had lost pressurization in his right glove during an ascent to 103,000 ft (19.5 miles, 31.4 kilometers). Despite the depressurization, Kittinger continued the mission, rationalizing that he was testing the suit and that the glove was not part of the mission, and he did not require any manual dexterity for the jump. His right hand became painful and useless and after he returned to the ground, his hand returned to normal. Kittinger wrote in *National Geographic* (November 1960):

> At 43,000 feet I find out [what can go wrong]. My right hand does not feel normal. I examine the pressure glove; its air bladder is not inflating. The prospect of exposing the hand to the near-vacuum of peak altitude causes me some concern. From my previous experiences, I know that the hand will swell, lose most of its circulation, and cause extreme pain....I decide to continue the ascent, without notifying ground control of my difficulty.[7]

Kittinger's decision was not particularly heroic. The glove's failure to compensate for the decreasing atmospheric pressure would not invalidate the test of the pressure suit. The MC-3A gloves were not designed to seal to the suit. The suit was only a partial pressure suit with the sole purpose of delivering a pilot to a lower altitude; it was not a sealed suit designed to deliver oxygen. Kittinger wore an oxygen mask for that purpose. One can assume that Kittinger understood very well what was happening to his hand. As a trained test pilot, Kittinger had prepared for emergencies, including the failure of a glove. If he had not personally worked in a vacuum chamber, he had read the reports from those technicians who had. Without the counterpressure from the gloves at over 100,000 feet, the gases that had been dissolved in his fluids and tissue were coming out of solution. This is the natural effect of low pressure that is often inaccurately referred to as boiling. In absence of the counterpressure of 14.7 psi, Kittinger's flesh was expanding, much in the way that a balloon would expand under those circumstances. In spite of the fact that he experienced great pain, Kittinger recovered from his ordeal almost immediately. He landed 13 minutes and 45 seconds after leaving the gondola. Three hours after landing, his swollen hand and his circulation returned to normal.[8]

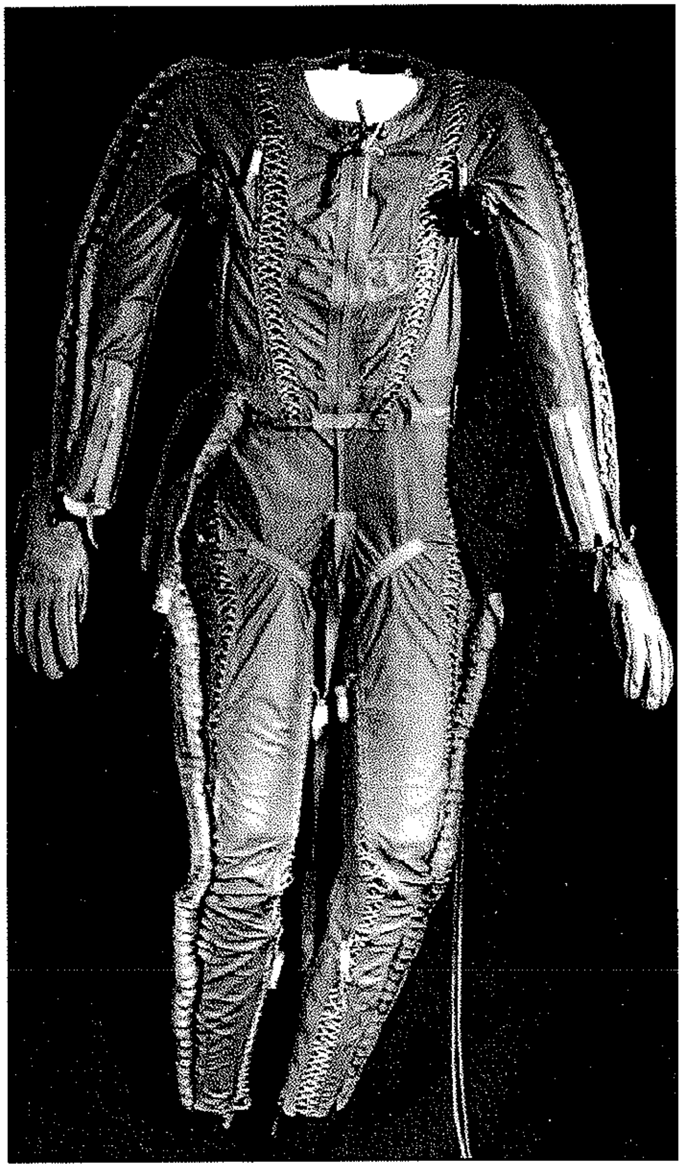

Figure 1. The David Clark Company MC-3A partial pressure suit. Courtesy: Smithsonian Institution

Jim LeBlanc in 1966 at JSC

Perhaps the most closely monitored account of what happens when a spacesuit fails has come from the experience of

Figure 2. An ILC Industries A5-L pressure suit. Courtesy: Smithsonian Institution

NASA Manned Spacecraft Center technician Jim LeBlanc. On 14 December 1966, LeBlanc was inside NASA's 8-foot altitude chamber that had been depressurized to the equivalent atmosphere at 150,000 feet (28 miles), miles higher than Joe Kittinger's parachute jump. His A5-L spacesuit (see Figure 2) was operating at the normal operational pressure of 3.8 pounds per square inch (psi) of oxygen. When the hose supplying oxygen to his suit was accidentally disconnected from a valve outside the chamber, the pressure in the suit almost immediately dropped to 0.1 psi. LeBlanc had almost no time to notice what was happening to him. In interviews after the incident, he recalled that his suit began to feel loose, and the pressure gauge on the suit registered 2.5 psi before noting that the saliva on his tongue started to bubble.[9] The pressure had dropped to the point that the air in his saliva was coming out of solution or "boiling." That was the last thing that LeBlanc remembered before seeing Henry Rotter standing over him in a partially repressurized chamber. He had immediately lost consciousness and was unaware of the rapid action that his colleagues took in order to save his life.

There is a lot of conjecture on what would have happened had LeBlanc's coworkers not dashed into the chamber before it was brought up to sea level pressure. Under normal circumstances repressurization and opening the chamber would have taken as much as 30 minutes, but they did it in a little over 1 minute, 87 seconds, to be precise.[10] LeBlanc's survival was probably facilitated by Rotter's decision to remove LeBlanc's gloves before moving him out of the chamber, letting oxygen into the suit through the wrists. Jim LeBlanc was fortunate and suffered no long-term ill effects from the incident. He did complain that his ears ached from rapid repressurization for days after, however.

Jim LeBlanc's accident did verify much of what physiologists thought about the consequences of rapid depressurization of a spacecraft. The immediate threat to LeBlanc's life was not the absence of pressure, but the lack of oxygen. His death would have been quick and undramatic had there not been technicians standing by to assist him. It took less than 15 seconds for LeBlanc to recognize that something was wrong. What he sensed was the lack of pressure in his system. Without the standard sea-level atmospheric pressure, the gases in his saliva had begun to escape, causing it to bubble. At that point it was too late for him to recognize or act against the fact that he had no oxygen to breathe.

1971 *Soyuz 11* Cosmonauts

On 7 June 1971, the USSR launched a crew of three cosmonauts, Vladislav Volkov, Georgi Dobrovolski, and Viktor Patsayev, aboard the *Soyuz 11* spacecraft on a mission to the *Salyut* orbiting space station. After a few stutters, this mission was intended to inaugurate a new era in Soviet human spaceflight. The original prime crew for *Soyuz 11* had consisted of Alexei Leonov, Valeri Kubasov, and Pyotr Kolodin. The backup crew replaced them after an anomalous x-ray indicated that Kubasov was harboring a tuberculosis infection. *Soyuz 11* was to complete the mission that the crew of the previous spacecraft had been unable to do. The cosmonauts Vladimir Shatalov, Aleksei Yeliseyev, and Nikolai Rukavishnikov navigated their *Soyuz 10* spacecraft to the *Salyut 1* station, yet during docking they ran into problems. They linked with the station and were able to achieve "soft dock" with *Salyut* on 22 April 1971. The "probe and drogue" docking mechanism worked, but the two craft failed to achieve "hard dock" by securing the docking collar. *Soyuz 10* returned to Earth two days later. These setbacks, notwithstanding, the June 1971 mission was slated to follow the successful re-inauguration of the Soyuz program.

The previous successful Soyuz missions that included Bergovoi's *Soyuz 3* and the subsequent joint missions of *Soyuz 4/5*, *6/7/8*, and the long duration mission of *Soyuz 9* had seemingly demonstrated that in spite of having lost the Moon race to the Americans, the Soviet human spaceflight program was charting its own course to a long-term orbiting space station. In previous Soyuz missions, cosmonauts had worn Yastreb spacesuits to facilitate crew transfers between spacecraft via external access. Up to that point, the docking adaptors had no inner passage.[11] The Yastreb suit was based on a full-pressure suit that Soviet pilots wore in reconnaissance aircraft. To that, Zvezda engineers added external thermal micrometeoroid layer and an independent life support system that supplied oxygen, temperature regulation and removed CO_2 by means of lithium hydroxide (LiOH).[12]

Once they entered the *Salyut* space station, the Soviet press celebrated the fact that Volkov, Dobrovolski, and Patsayev managed the hard dock that had eluded their immediate predecessors. They remained aboard for 22 days. Their activities included live television broadcasts, Earth observations, and photography. And even when a fire broke out on day 11 of their mission, mission control allowed them to continue with their flight plan. The *Soyuz 11* crew broke the 18-day mission record of *Soyuz 9* and undocked from the space station and returned to Earth on 30 July 1971. When recovery crews arrived at the landing site and opened the landing capsule, they discovered that all three cosmonauts were dead, two firmly strapped into their seats. Even though the Soviets were characteristically cagey about the design and performance of their space hardware, the informal story soon spread that a breathing ventilation valve had failed, depressurizing the spacecraft.[13] The valve had opened instead of automatically adjusting cabin pressure at an altitude of 168 kilometers (104 mi), and the gradual loss of pressure was fatal within seconds.[14]

What had not been discussed through the celebration of the accomplishments had been the fact that in their zeal to chart a new space station program, mission planners had made the fateful decision to send crews of three instead of two on the Soyuz to the *Salyut*. Previous Soyuz crews had worn spacesuits, anticipating spacewalks and external access to other spacecraft, or, in the case of *Soyuz 9*, had no docking maneuvers that might have disrupted the function of equalization valves. In the case of *Soyuz 10* and *Soyuz 11*, in order to squeeze three people into a spacecraft that had previously only served a crew of two, the cosmonauts had to forego spacesuits. This plan was not beyond the Soviet's experience of risk. In 1964, in order to preempt the US Gemini program, they had launched a crew of three in a modified single passenger Vostok spacecraft without the back-up support of spacesuits. The Voskhod crew had returned safely without incident. If they had concerns over launching a crew without the backup of spacesuits, they likely reassured themselves with past performance of the spacecraft.

The immediate consequence of the deaths of Patsaev, Volkov, and Dobrovolskii was NASA's decision requiring that the *Apollo 15* crew: David Scott, James Irwin, and Alfred Worden, would fully suit up when they jettisoned the ascent stage of the lunar module after Scott and Irwin returned to the command module. NASA issued a press release stating that the decision was made as a consequence of "re-evaluation of pressure suit requirements during different phases of the *Apollo 15* mission."[15] They had clearly decided to err on the side of safety during any event that might compromise the spacecraft's seal integrity. The Apollo A7-L suits were then designated to play their role as emergency, "Get–me–down" suits; a second and almost forgotten role of these moon–walking spacesuits.

The longer term effect of the loss of the *Soyuz 11* crew was the redesign of the Soyuz spacecraft and its downgrading to a two-person craft for the next nine years. Part of the redesign included the installation of Zvezda-designed Kazbek shock–absorbing seats that would not accommodate the previous suit designs that included the Vostok-era SK (Skafandr kosmicheskii), Leonov's Berkut, and the previously used Soyuz Yastreb suits. All were too bulky to allow continuous use inside a spacecraft.[16] Zvezda engineers adopted the Sokol aviation lightweight full pressure suits with an incorporated soft helmet, thus reducing the bulk and rigidity of the neck ring and hard helmet to fit into the couch. More important, the incident brought about new procedures that required all cosmonauts to wear a Sokol-type spacesuit for launch and entry in any Soyuz spacecraft. This rule remains in place until this day, when all astronauts, cosmonauts, and partners traveling to the *International Space Station* aboard the Soyuz TMA are fitted and wear a Sokol-KV2 spacesuit for launch, docking, and all emergency activities.

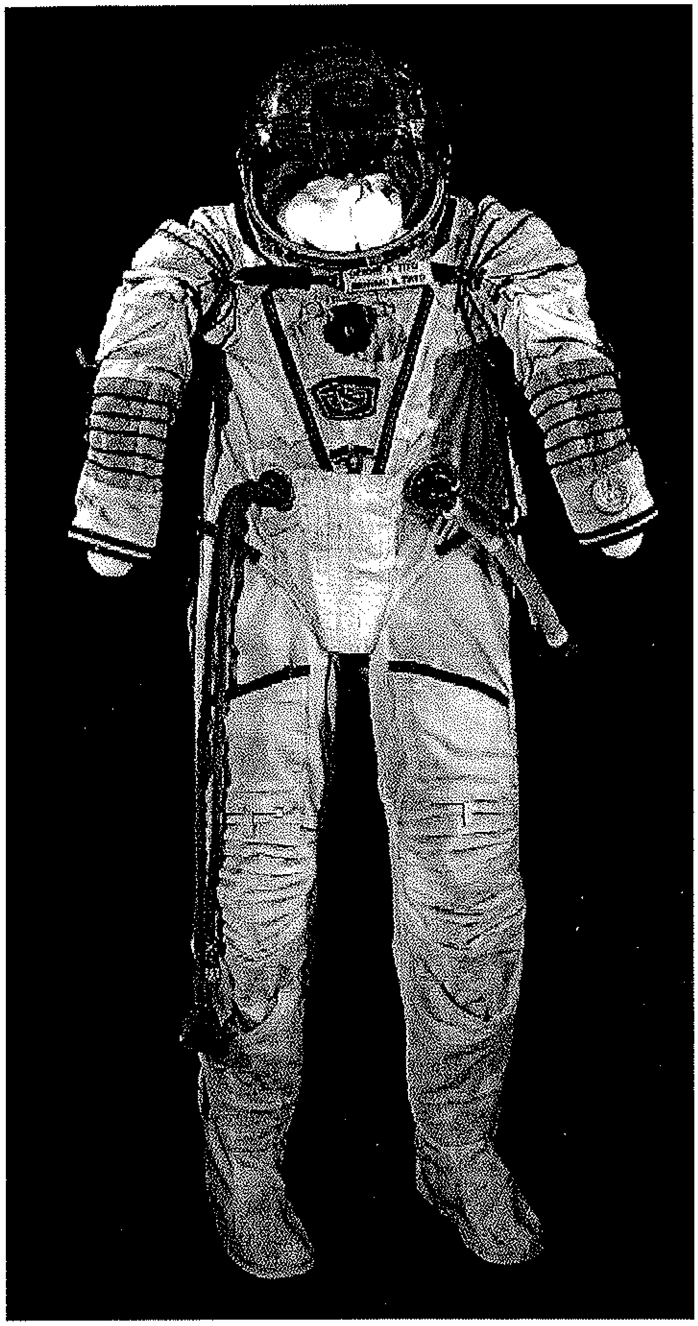

Figure 3. Dennis Tito's Zvezda Sokol KV-2 emergency pressure suit; now required for all Soyuz launches and entries.
Courtesy: Smithsonian Institution

1991 STS–37 EVA

Even when sound and redundant spacesuit policies are in place, accidents can occur and spacesuits can fail. Optimal glove design has been a challenge for pressure suit engineers

Figure 4. The restraint assembly for a Series 4000 glove for the Space Shuttle EVA suit. This glove was made prior to the redesign to the Series 5000.
Courtesy: Smithsonian Institution

for generations. The challenge grew as programs called for increased manual activities from astronauts in space. From Gemini to Apollo, astronauts had to increase their manual dexterity from climbing out and back into the spacecraft and taking pictures to simulating geological surveys on the surface of the Moon. With these demands came increasing improvements in spacesuit gloves, as the design tried to find a compromise between strength and durability and the tactile sense necessary for any manual activity. The demands increased even further when astronauts were assigned construction and repair missions in the open vacuum of space.

On 8 April 1991, Jerry L. Ross and Jay Apt made the first scheduled EVA since STS-61-B in November 1985. The purpose of the spacewalk from the orbiter *Atlantis* was to test methods of moving crewmembers and equipment around the future *Space Station Freedom*. One of the experiments was to evaluate manual, mechanical, and electrical power methods of moving carts around the outside of large structures in space. Although all three methods worked, the astronauts reported that propelling the cart manually or hand-over-hand worked best. With both EVAs, Ross and Apt logged 10 hours and 49 minutes walking in space during STS-37. The crewmembers also reported success with secondary experiments.[17] During the course of the spacewalk, the palm restraint in one of the astronaut's gloves came loose and migrated until it punched a hole in the pressure bladder between his thumb and forefinger. It was not explosive decompression but a small 1/8 inch hole caused the first injury from a suit incident. The astronaut didn't even know the puncture had occurred. After he got back in, he noticed there was a painful red mark on his hand. The skin of the astronaut's hand partially sealed the opening. He bled into space, and at the same time his coagulating blood sealed the opening enough that the bar was retained inside the hole.[18]

In their never-ending quest for a durable glove that also maximizes tactile sensation, ILC Dover had redesigned a Series 4000 glove from the spacesuit to accommodate higher pressure, modified restraint system, and bladder for better dexterity.[19] One of the features was a low torque pressure thumb and a redesigned cover layer. NASA had made the decision to fly the glove specifically to be evaluated for performance on this mission. The glove combined a tight fit and high pressure to create a glove that would allow hand movement and minimize discomfort. However, due to its tight fit, astronauts had to constantly readjust the restraint bar along the palm. The constant readjustment caused the bar to become malformed, much in the same way that a wire clothes hanger loses its shape after multiple bendings.[20] During one of the EVAs, the distorted restraint bar punctured the seal of one of the astronauts' gloves (the name is undisclosed, but it was either Ross or Apt). However, the astronaut's hand partially sealed the hole, resulting in no detectable depressurization. In fact, the puncture was not noticed until after the spacewalkers were safely inside *Atlantis*. The result was a redesign of the Shuttle EMU glove design to reinforce the padding along the restraint bar and review their quality control procedures.[21]

2013 Luca Parmitano

On 9 July 2013, Italian astronaut Luca Parmitano experienced an almost unthinkable failure in his spacesuit.[22] The failure was unthinkable because it was not one that is normally expected in a spacesuit either in popular culture or in the routine emergency contingencies that astronauts prepare for before flight. There was no breech to the outer barrier of his suit. He did not lose pressure or oxygen. Luca Parmitano nearly drowned inside his spacesuit.

Parmitano had prepared for his EVA through hours of practice. He had anticipated fatigue from working his fingers against the pressurized gloves to attach cables for an hour. What he had not anticipated was a wet sensation starting at his upper back. At first he thought that the water was sweat or coming from a leak in his in-suit drinking device. But that water was far too cold to be perspiration and too abundant to be coming from a barely-visible-to-the-naked-eye hole in the plastic water bladder. And Parmitano did not have time to troubleshoot his suit failure while still outside the airlock.

The remarkable thing about Parmitano's experience is that he would have neither been in such great danger or might not have been aware of his problem had he experienced the type of pressure suit breech that others had experienced. A breech would have directed the water away from his skin surface and toward the leak. This water, that was pouring out of a clogged relief valve supplied from his life support backpack inside his spacesuit, was creeping along the back of his head; filled his ears, making his communications carrier useless and instructions inaudible; and rose up over his face, first in his eyes.[23] By the time he was experiencing stinging from the anti-fogging coating inside his helmet, Parmitano feared that his next breath would draw the water into his lungs.

It is a small coincidence that

Canadian astronaut Chris Hadfield has demonstrated the effect of surface tension on water in zero gravity in popular video months before Parmitano's incident by wringing out a washcloth and demonstrating that the water would retain its shape, clinging to his hands like a gel.[24] The physical principles that Hadfield had demonstrated and that Parmitano experienced were all but impossible to simulate here on Earth. NASA's Neutral Buoyancy Laboratory (NBL) prepares astronauts for operating in an environment in which Earth gravity is not the overwhelming force under which they are working. Parabolic flights can simulate near zero gravity for a few minutes, but are not even adequate to demonstrate the prolonged effects of changes in water's behavior under those conditions. It is hard to imagine that Parmitano was thinking about this classroom demonstration as he waited for his colleague to rescue him and guide him back to the airlock of the *ISS*.

Luca Parmitano's experience is a reminder that for all the imagination and computer graphics available to our 21st century minds, the greatest danger and fear remains that basic fear of loss of air to breathe, either through suffocating or drowning. In his post-EVA blog entry, Parmitano summed up the very real horror that he experienced and explained it within the context of his chosen career:

> Space is a harsh, inhospitable frontier and we are explorers, not colonisers. The skills of our engineers and the technology surrounding us make things appear simple when they are not, and perhaps we forget this sometimes. Better not to forget.[25]

His distinction between explorers and colonizers is important. It points out the difference between science fiction and reality. In science fiction, the thousand little iterations of malfunctions and unanticipated situations have been worked out in advance. It is the harsh reality of explorers that they have to be prepared for those situations that have not yet been considered.[26]

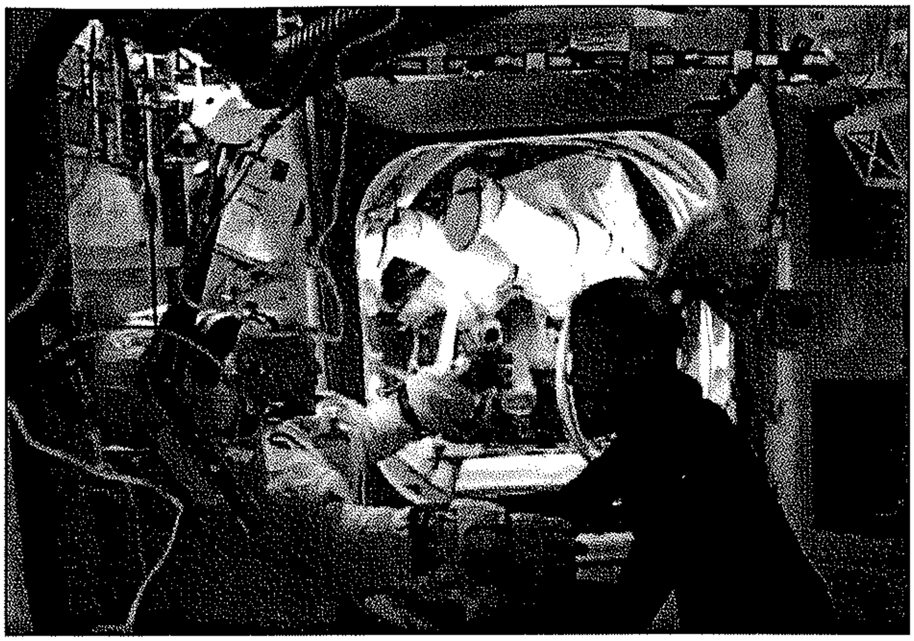

Figure 5: Astronaut Karen Nyberg (right) assists Italian Luca Parmitano after he returned to the *ISS* following an aborted spacewalk on 9 July 2013. Credit: NASA

Conclusion

From the 80 years of the development of pressure suits, certain properties of spacesuit failure have been well understood. Pilots and astronauts have trained for those contingencies repeatedly to the point of making their reactions to what could potentially be a catastrophe almost routine. The planning has largely resulted from scientific knowledge gained here on Earth. Physiologically, doctors have understood the process of decompression and it effects on the human body for over a century. Experience in caisson work in the 19th century, mining, and deep sea diving in the last century have provided opportunities to study what happens when mammals suddenly lose oxygen or when its pressure changes dramatically and quickly. In the 20th century, there have been many physicians who have treated more than a few patients experiencing scuba accidents from too rapid ascents. By and large, the most critical issue that they address has been dealing with the solubility of critical gases in the blood (i.e., nitrogen and oxygen). Blood doesn't actually "boil," *per se*, but what popular culture has perceived as boiling is the rapid release of nitrogen gases from the blood under very low ambient pressure.

Scientists have explored far more dramatic effects of the loss of oxygen on the body through simulations. Through the use of vacuum simulators, they have learned that the body doesn't swell and explode in absence of an atmosphere. To the contrary, the lack of atmosphere in a vacuum has an insulating property. A dead, warm body would tend to remain in that state, in absence of colliding molecules to pull energy away from it. For the same reasons that Quaid's eyes would not bulge, Dave Bowman was able to surf the air from one craft to another in open space. And likewise, Joe Kittinger and the STS-37 crewmember's glove failures were isolated and non-life threatening events

Reality usually is less dramatic than science fiction. In real life, unlike fictional spacewalking scenarios, scientists and technicians have prepared for and rehearsed every conceivable scenario. They have trained to observe subtle hints to assure that suits are working properly. In order to know what to look for they must understand the science and look for the symptoms. In order to save lives, the symptoms have to be caught early. The questions remains if science fiction can do damage to the public understanding of science and if there is a limit to the scientific imagination that can cause planners to overlook plausible scenarios that are beyond their means to simulate. The persistence of the boiling blood concept in popular culture would indicate that the answer to the former is yes. The answer to the latter question is more ambiguous. Real life drama that is not obvious or easily simulated, means failures will continue to occur. Participant's cognizance that they are merely temporary residents in space will incline them to fall back onto well-rehearsed worst-case plans, as Luca Parmitano did. It saved his life.

This conclusion takes us back to Konstantin Tsiolkovsky and his warning against fantastic science fiction and a call for more realistic science fiction. Tsiolkovsky feared for the young science of aviation and rocketry succumbing to popular ignorance. The real scientific life without a spacesuit might not always be as compelling to a movie director or a cinematographer, but it is short, potentially deadly and very dramatic to real live astronauts and cosmonauts.

About the Author

Cathleen Lewis is curator of International Space Programs and Spacesuits at the Smithsonian Institution's National Air and Space Museum, specializing in Soviet and Russian programs. Her current research is on the history of the public and popular culture of Russian fascination with the idea of human spaceflight in the Soviet Union. She has written about the artifacts in the Smithsonian's Soviet and Russian collection and has published articles comparing the Soviet and American approaches to exhibiting spaceflight during the Space Race and the history of film portrayals of spaceflight prior to Yuri Gagarin's historic flight. She is also working on a comparative history of the development of American and Russian spacesuits.

Notes

1 Stanley Kubrick, *2001: A Space Odyssey* (USA/UK: 1968).

2 Stanley Kubrick might not have been aware of Konstantin Tsiolkovsky's writings on science fiction dating to the end of the 19th century, but there is good evidence that he was acquainted with the filmmaking of another Russian science-fiction devotee, Pavel Klushantsev. Klushantsev was a relatively unknown documentary filmmaker in 1950s and 1960s USSR. He specialized in space-themed footage that created special effects that he designed on the basis of correspondence that he had with Soviet space scientists. His fans in the West included Roger Corman and Stanley Kubrick.

3 Arthur C. Clarke, *2001: A Space Odyssey* (New American Library, 1968).

4 Paul Verhoeven, *Total Recall* (USA: 1990).

5 Philip K. Dick, "We Can Remember It for You Wholesale," in *The Philip K. Dick Reader* (Citadel Press, 1987).

6 Dennis R. Jenkins, *Dressing for Altitude: U.S. Aviation Pressure Suits—Wiley Post to Space Shuttle* (National Aeronautics and Space Administration, 2012), 160-165.

7 Joseph W. Kittinger Jr., "The Long, Lonely Leap," *National Geographic* (December 1960).

8 Giles Clément, "Fundamentals of Space Medicine," James R. Wertz, ed., *The Space Technology Library* (Springer, 2005), 265.

9 "Two MSC Employees Commended for Rescue in Chamber Emergency," *Roundup*, NASA Manned Spacecraft Center, Houston, Texas, 4 January 1967, 3.

10 *Roundup*, 3.

11 Abramov and Skoog, *Russian Spacesuits* (Springer Praxis, 2003), 125.

12 Abramov and Skoog, 87.

13 Key to interpreting Soviet statements immediately after the deaths was the emphatic denial that there had been more sinister reasons for the death than a single point of failure. Tom Stafford's book and press citations of the time point to a single, spacecraft point of failure.

14 Arnauld E. Nicogossian, *Space Physiology and Medicine* (US Government Printing Office, 1982).

15 Thomas O'Toole, "*Apollo 15* Crewmen to Suit Up to Avert *Soyuz 11* Disaster," *The Washington Post* (20 July 1971), A3.

16 Abramov and Skoog, 125-126.

17 C. E. Whitsett, Lisa A. Gall, Luis A. Trevino, *EVA Results of Shuttle Mission STS-37* (Seattle, WA; Johnson Space Center; Langley Research Center, 1992).

18 Clément., 265.

19 David A. Graziosi, "ILC Dover Spacesuit Glove History," 4.

20 Kenneth S. Thomas and Harold J. McMann, *U.S. Spacesuits* (Chichester, UK: Springer Praxis, 2006), 280.

21 Graziosi, "ILC Dover Spacesuit Glove History," 4.

22 *Drowning in Space* by Joel Achenbach, Published 22 August 2013 at 3:13 pm http://www.washingtonpost.com/blogs/achenblog/wp/2013/08/22/drowning-in-space/ and Parmitano, Luca. "EVA 23: Exploring the Frontier." In Luca Parmitano's European Space Agency blog: European Space Agency, 2013.

23 NASA has not completed its investigation of the incident, but its focus has been exclusively outside the spacesuit assembly (SSA) gasbag. This means that the source of the leak was outside the pressure garment and its contents. The contents include the in-suit drinking device and the Liquid Cooling and Ventilation Assembly (LCVA), which were the only other sources of water.

24 Chris Hadfield, 2013. "Wet Washcloth in Space—What Happens When You Wring It?," Video from Space. Online Video, http://www.youtube.com/watch?v=lMtXfwk7PXg (accessed 23 August 2013).

25 Luca Parmitano, "Eva 23: Exploring the Frontier," In Luca Parmitano's European Space Agency blog: European Space Agency, 2013.

26 NASA has published a redacted incident report on the Parmitano incident that analyzes the direct and indirect causes and makes preliminary recommendations for new procedures for the use of the suit. NASA, "International Space Station (ISS) EVA Suit Water Intrusion High Visibility Close Call," IRIS Case Number S-1013-199-00005, Date of Mishap, 16 July 2013. www.nasa.gov/sites/default/files/files/Suit_Water_Intrusion_Mishap_Investigation_Report.pdf (accessed 30 March 2014), 140-144.